NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4009

SOME RESEARCH RESULTS ON SANDWICH STRUCTURES

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SUMMARY

The results of compressive-buckling tests of steel sandwich plates are given, and the significant parameters which affect the strength of the plates are discussed. The various types of sandwich construction are shown to be comparable on a weight-strength basis with conventional high-strength aluminum-alloy construction.

INTRODUCTION

The use of high-density, heat-resistant materials in modern aircraft has served to reemphasize the need for lightweight methods of construction. One such method receiving wide attention is sandwich construction which permits almost full utilization of the strength of thin gages of materials. Success of this approach is to a large extent dependent upon advances in production techniques and practical engineering experience. For these reasons a number of sandwich configurations have evolved, some of which are shown in figure 1. The honeycomb sandwich has been produced by adhesive bonding, brazing, and welding techniques. In high-temperature materials there is considerable interest in the welding approach and attention has, therefore, been directed toward other configurations which are more amenable to welding. Representative of these configurations are the truss-core, tube-core, and web-core sandwiches also shown in figure 1. These configurations have the common characteristic that the core elements can be joined to the faces by welding along parallel longitudinal lines. Certain obvious differences exist between these configurations and the honeycomb; for example, they are more directional in their stiffness and strength properties. They require a heavier core to achieve comparable panel thicknesses, but the core carries direct loads and provides a high shear strength. The core also provides natural passages for the circulation of coolants in applications where this may be desirable. The behavior of the truss-core sandwich is typical of this group and is considered along with the honeycomb sandwich in this paper.

SYMBOLS

b	plate width
D	plate flexual stiffness per unit width
D_Q	plate shear stiffness per unit width
E	Young's modulus of elasticity
h	overall height of sandwich
k	plate-buckling coefficient
l	panel length
P_i	compressive load per unit width
t	plate-element thickness
η	plasticity reduction factor
θ	angle between face sheet and core element
μ	Poisson's ratio
σ	stress
σ_{cr}	buckling stress

Subscripts:

c	core
f	face sheet
1	upper face
2	lower face

EXPERIMENT

Honeycomb construction effectively increases the thickness of the sandwich plate which results in a high overall bending stiffness as compared with an equivalent-weight plate of solid material. At the same time, however, the light core tends to make a sandwich sensitive to concentrated loads and causes shearing deformations to play an important role in determining the stress that a sandwich plate can carry. Because of this effect, sandwich development has required considerable experimental work using special test techniques and fixtures.

Test Technique

A fixture that was found to be suitable for a simple test of the strength of a sandwich panel in compression is illustrated in figure 2. The panel is loaded on its ends by a testing machine, and the panel edges are alined by a fixture designed to give simple support. A cross-sectional view of the panel and fixture is shown in figure 3. The I-beam and knife edges prevent lateral deflection of the panel edges but permit rotation. They can be adjusted to accommodate panels of different thickness and width. Clearance between the fixture and the testing machine permits shortening of the panel without loading the fixture.

The sandwich plate shown in figure 2 has a honeycomb core. For this type of sandwich it was found necessary to reinforce the panel at the loaded ends to prevent end failures. The light areas of the test specimen are externally applied doubler plates which are adhesive-bonded to the panel. It is considered significant that in tests of truss-core sandwich no special end reinforcement was required. This is attributed to the higher shear strength of the core of this construction.

Test Results

Panels.- Test results for some honeycomb panels are compared in figure 4 with the buckling theory of reference 1. These panels varied in thickness from 1/4 inch to 3/4 inch with face-sheet thicknesses of 0.015 inch to 0.064 inch. The compressive buckling-stress coefficient is plotted as a function of a shear-flexibility parameter. Theory predicts a large loss in panel buckling strength as core shear flexibility increases. If the shear stiffness D_Q of the panel is large, the buckling-stress coefficient approaches the value of 4 which is associated with solid plates. Theory is capable of predicting the influence of the geometrical quantities which make up the shear-flexibility parameter as is illustrated by the open test points for both brazed and adhesive-bonded steel honeycomb panels. The core density associated with these points was

$8\frac{1}{2}$ lb/cu ft (1/4-inch cell with 0.002-inch foil) and 12 lb/cu ft (1/4-inch cell with 0.003-inch foil). However, when panels having a core density of $6\frac{3}{4}$ lb/cu ft (1/4-inch cell with 0.0015-inch foil) were tested, predicted strengths were not consistently obtained as indicated by the darkened test points. These low points are believed to be caused by the low shear strength associated with the lightest core. The influence of core shear strength is not included in buckling theory. The loss in buckling strength for these panels is much greater than the reduction in weight over a panel which had a heavier core but sustained the predicted load. Hence, on a weight-efficiency basis as well as from the standpoint of obtaining consistent and reliable results, these tests indicate that adhesive-bonded cores should have a density greater than $6\frac{3}{4}$ lb/cu ft. In the sandwiches with the heavier cores, the stresses in the face sheets varied up to 200,000 psi, the compressive yield stress of the material tested.

Beams.- Since the matter of core density is an important factor in determining the weight of honeycomb panels, further tests have been made in which sandwich panels were used as the compression covers of box beams in bending. Figure 5 is a photograph of one of the beams after a compression failure of the sandwich cover. Of the three beams tested to date, only the one having a sandwich with a core density of 12 lb/cu ft approached the load predicted by theory (17 percent less than theory). The remaining two beams had core densities of $8\frac{1}{2}$ and $6\frac{3}{4}$ lb/cu ft and failed at loads considerably less than the predicted ones. These results suggest that, to achieve adequate core shear strength, heavier cores may be required for a practical structure than for simple compression tests under more ideal conditions.

LOCAL BUCKLING OF TRUSS-CORE SANDWICHES

Plate-buckling theory has been applied to truss-core sandwich plates and the available test results indicate that the theory is again adequate. With the truss-core sandwich no problems with core shear stiffness or strength were encountered because of the higher core densities required to prevent local buckling of the individual plate elements of the sandwich configuration. The local buckling stress can be calculated with the aid of a diagram such as that shown in figure 6. By knowing the local buckling stress as well as the overall plate instability stress as a function of sandwich dimensions the proportions can be varied to obtain the most efficient sandwich for any given loading condition. In figure 6 the buckling coefficient for local instability of the sandwich configuration is plotted against the ratio of core-element thickness to face-sheet thickness over a range of values found to give efficient proportions. It should be noted that the core elements are of the same order of thickness as the face sheets in contrast to the foil in honeycomb cores which may be only a fraction of the thickness of the face sheets. Inasmuch as the sandwich is orthotropic, the buckling-stress coefficient is given for compression in both the longitudinal direction indicated by the upper curves and the transverse direction indicated by the lower curves. A lower strength is obtained for the transverse loading inasmuch as the face plates are subject to column failure between truss-panel points. In both cases, the buckling-stress coefficient is raised because of interference restraints caused by the triangular arrangement of the members. The values indicated in figure 6 have been substantiated by crippling tests on small specimens such as that shown in figure 7. This particular specimen is of welded construction, 17-7 PH stainless steel, and sustained a stress of 185,000 psi at failure.

By using figure 6, plate proportions can be adjusted so that local buckling of the sandwich elements is equal to or greater than the overall plate-buckling stress. For example, if it is desired to achieve a longitudinal-compression stress of 180,000 psi (a typical value for the yield stress of high-strength steel), the proportions given on the left-hand portion of figure 6 meet the requirements; also given is the critical compressive stress in the transverse direction which is almost two-thirds the value for the longitudinal direction. The overall height of the sandwich, indicated by the ratio $h/t_f = 15$, is such that a very favorable weight efficiency is obtained for panels of this sandwich loaded in edge compression.

EFFICIENCY OF SANDWICH CONSTRUCTION

The weight of unstiffened plates, sandwiches, and stiffened panels subjected to longitudinal-compressive stress is plotted as a function of the appropriate structural index in figure 8. The weight of these structures can be compared at identical values of the structural index inasmuch as the plate width b and panel length l are simply the support spacing in an actual structure. For this particular plot, the units are such that, if the ordinate is multiplied by the support spacing, the weight is given directly in pounds per square foot of surface. For example, at an ordinate value of 0.2, a plate 10 inches wide would weigh 0.2 times 10 (or 2 lb/sq ft).

The weight efficiency of the honeycomb-sandwich construction taken from reference 2 has been calculated by assuming that a core density of 10 lb/cu ft was necessary to obtain the stresses indicated by theory.

The most efficient proportions for the truss-core sandwich involve core densities varying from 30 to 50 lb/cu ft. Despite the greater core density for the truss-core sandwich, there is little difference in weight between the two types of sandwich construction; with the honeycomb sandwich more efficient at low values of the structural index and because of the load-carrying core, the truss-core sandwich is more efficient at the higher values. Also shown in figure 8 are the weight-efficiency curves for high-strength aluminum-alloy plates that would occur in multispar construction and for conventional stiffened-panel construction. It appears that under compressive loadings sandwich construction in steel is comparable in weight to efficient conventional construction in aluminum alloy.

THERMAL STRESSES IN SANDWICH PLATES

A consideration of the response of sandwich plates to transient heating indicates that certain adjustments to sandwich proportions may be desirable to minimize the effect of thermal stresses. For example, in figure 9 are shown the results of thermal-stress calculations for a typical sandwich which is heated on one face to 800° F at a rate of 8° F per second. Heat is transferred to the other face by conduction and radiation. The sandwich is assumed to be constrained to remain flat, and the resulting maximum thermal stress in the two faces is plotted against the thickness ratio of the two faces. This ratio was varied while holding the total weight of the sandwich constant.

For equal-thickness faces, the tension stress in the cooler face is equal to the compression stress in the heated face: As the thickness of the cooler face is decreased, relatively little change occurs in the tension stress while the compression stress in the heated face is reduced considerably. This favorable alteration in the thermal stresses is due partially to a reduction in the maximum temperature difference between the two faces and partially to the change in the relative areas of the faces. The decrease in compressive thermal stress permits an increase in load stress to be carried before buckling of the sandwich. In addition, the more even distribution of temperature through the thickness of the sandwich permits the absorption of a greater quantity of heat before the hotter face exceeds its allowable temperature.

CONCLUDING REMARKS

A few of the factors which affect the design of any particular sandwich configuration have been presented. For honeycomb construction, the core should be of sufficient stiffness to give a high buckling coefficient in order to obtain a minimum-weight sandwich. In addition, the core should be of adequate strength to prevent premature core failures and insure reliable results. For sandwiches such as the truss core, tube core, or web core, shear strength or stiffness is generally no problem; but the main consideration is proportioning the sandwich so that overall plate instability is not preceded by local buckling or crippling. Sandwiches of this type can be proportioned so that they compare favorably with honeycomb construction on a weight-strength basis. For elevated-temperature applications, a sandwich with a thicker outer face appears better able to cope with the effects of heating and restrained expansion.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 6, 1957.

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2. Johnson, Aldie E., Jr., and Semonian, Joseph W.: A Study of the Efficiency of High-Strength, Steel, Cellular-Core Sandwich Plates in Compression. NACA TN 3751, 1956.

SANDWICH CONFIGURATIONS

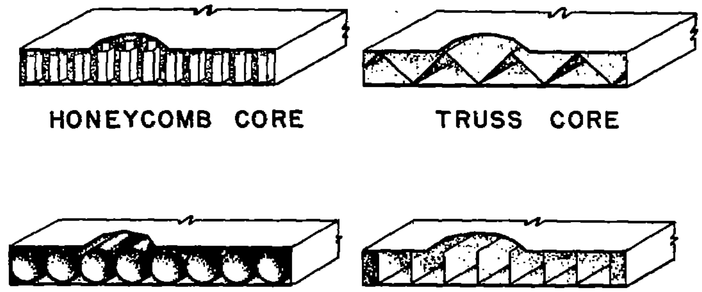

Figure 1

TEST SETUP

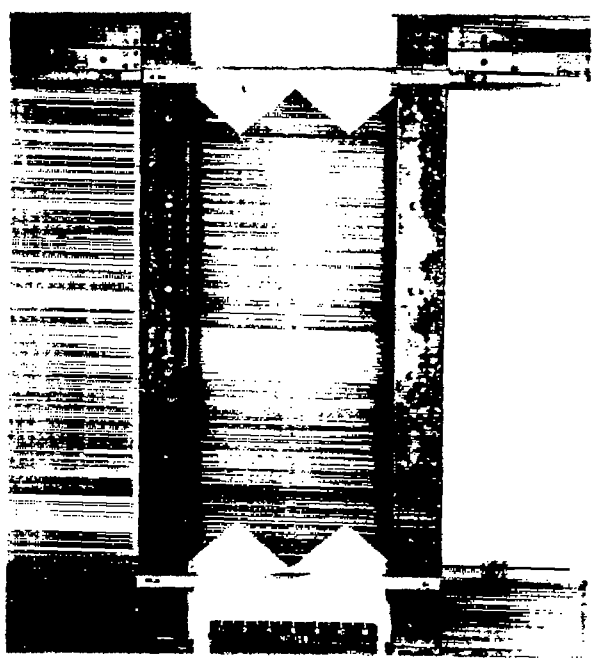

Figure 2 L-97141.1

CROSS SECTION OF FIXTURE AND SPECIMEN

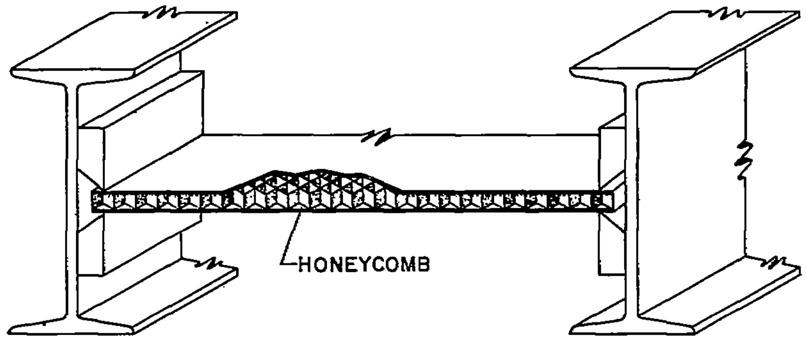

Figure 3

BUCKLING COEFFICIENTS FOR SANDWICH PLATES

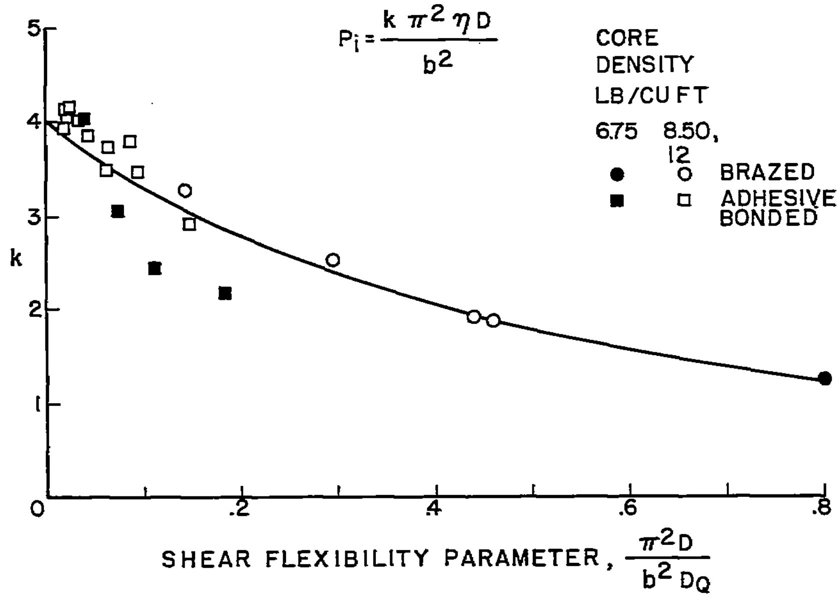

Figure 4

SANDWICH BOX BEAM AFTER FAILURE

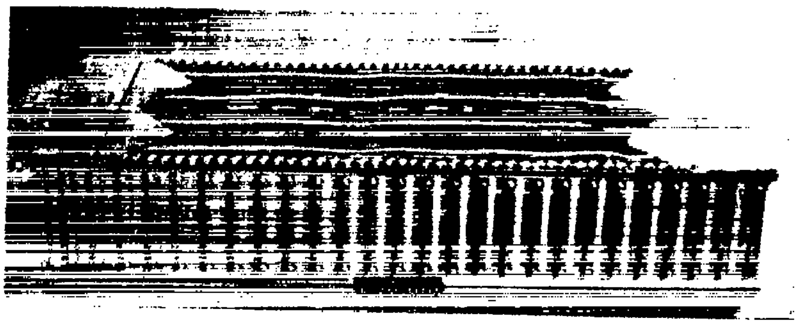

Figure 5 L-57-650.1

BUCKLING OF TRUSS-CORE SANDWICH ELEMENTS

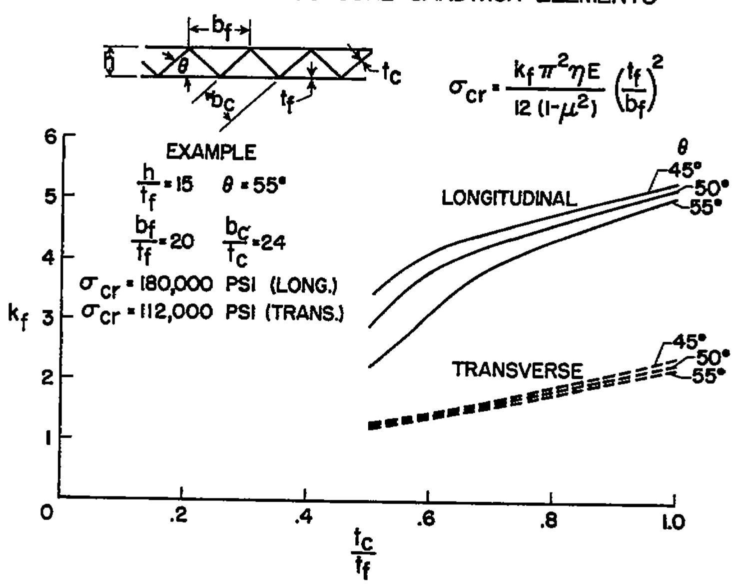

Figure 6

CRIPPLING SPECIMEN

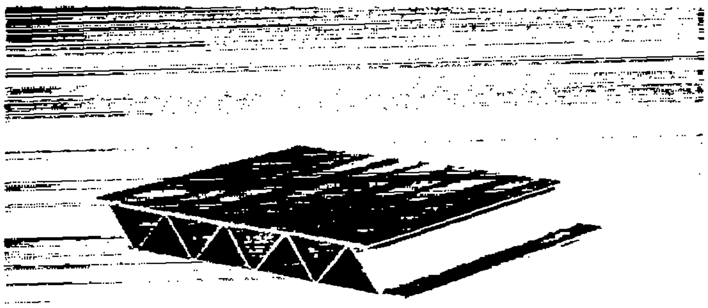

Figure 7 L-57-95.1

WEIGHT-STRENGTH CURVES

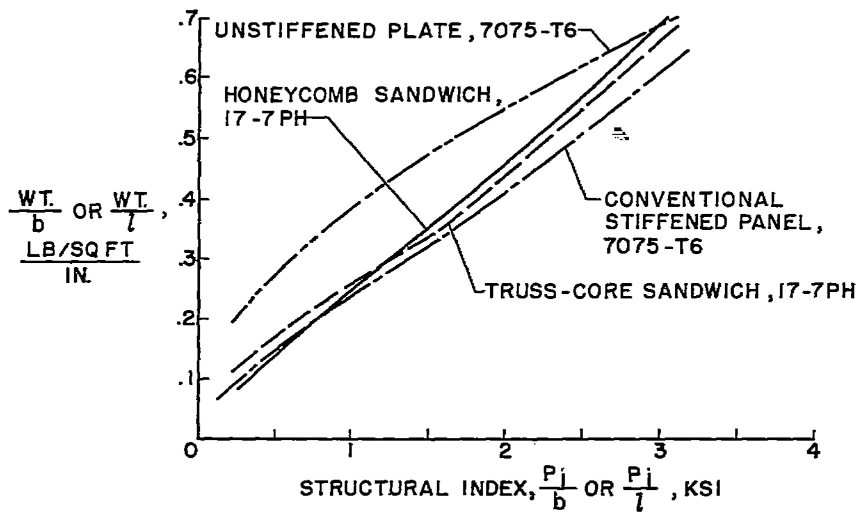

Figure 8

EFFECT OF SANDWICH DIMENSIONS ON THERMAL STRESSES

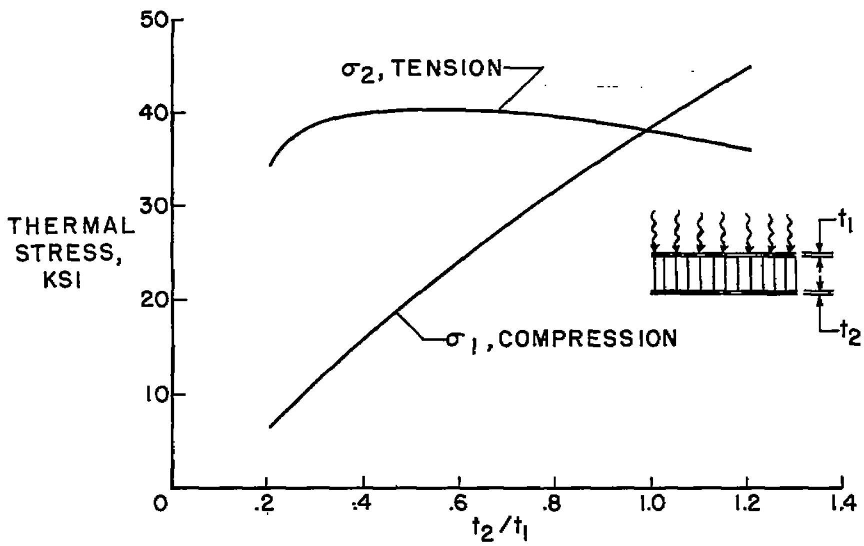

Figure 9